Chapter 6
Design Analysis and Detail Requirements

6-1. Gate Analysis Methods

a. General. It is the responsibility of the structural engineer to determine the appropriate level of analysis. There are many methods of analysis, both hand calculations and advanced computer programs, that will aid the engineer to obtain the optimum design of the gate. When using computer analyses, it is important for the structural engineer to understand the input parameters such as boundary conditions, material properties, and loading. Likewise, careful review of the output should show agreement with preliminary simplified calculations and simple statics checks.

b. Structural idealization. During analyses of vertical lift gates, consideration must be given to the methods of sealing, bearing, and hoisting to assure all loads are properly transferred to the guides, seals, plates, or rollers. Proper structural idealization of the boundary conditions will also ensure that the gate will perform as depicted in the structural model. For most vertical lift gates, two vertical sides and the top will bear against a downstream embedded bearing plate, with the bottom seal resting vertically on the bottom sill plate. For hydrostatic loads, the reaction components are orthogonal to the bearing face and are modeled as rollers with no resistance to rotation. Seal friction or plate bearing friction will ensure structural stability in the out-of-plane loading direction. In most cases where the gate rests on the sill, the bottom bearing surface should be modeled as having one vertical reaction component with the remaining degrees of freedom able to translate and rotate. Where the gate may be subjected to large changes in ambient conditions, restraint forces caused by friction should be examined to determine the magnitude of these forces that may induce additional stresses in the members and joints. This could lead to fatigue cracking problems if not properly addressed. These thermal forces would most likely occur in large navigation lock gates where the skin plate is subjected to cold water, while the other side is exposed to hot ambient conditions. In the case of the old downstream vertical lift gate at Ice Harbor Lock and Dam, restraint forces due to thermal differentials were studied. Analysis indicated that restraint forces increase stress from 206 to 310 MPa (30 to 45 ksi) to the main tension tie girders. This could play a significant role when the stress category for fatigue considerations is being determined.

c. Preliminary methods. Preliminary analyses are performed to determine the best framing method that will minimize the weight of the gate and still meet serviceability and physical restraints imposed by other structural features. The overall dimensions will be determined from the physical requirements of the lock, intake, bulkhead slot, or spillway. These methods are generally employed during reconnaissance and feasibility level studies. Preliminary calculations should also consider fatigue and fracture control requirements discussed in Chapters 3, 4, and 5. Overhead lift gates used in navigation locks have been employed for high heads where it is more efficient to use tension tie arches or trusses. For these types of gates, the depth of the arch or truss combined with the horizontal spacing of the main structural framing will determine the size of the members. Submerged gates, spillway crest, and emergency closure gates generally use plate girders or wide flanges for the main load-carrying members. As in the case of the overhead lift gates, the skin plate thickness and spacing of the main load-carrying girders will determine the size of the members. Several trial analyses may be required to obtain optimal spacing of main framing members and skin plate thickness. Skin plates are discussed in further detail in paragraph 6-2*a*. It is beneficial to pattern trial framing based on existing structures; however, the designer is cautioned that most of the existing gates have not been designed using current fatigue criteria. In general, reductions in stress for fatigue will generally decrease girder spacing, require different connections and member shapes, or increase their size. Initial methods of analysis for this type of gate should use simple two-dimensional models. These methods include hand computations or simple two-dimensional frame analysis using readily available computer programs.

d. Detailed analyses. These include the analysis of the gate in sufficient detail to determine final member sizes and connections for the gate. Because structural analysis software has become widely accepted and more user friendly, can provide higher order analysis, and can be executed on most personal computers, it may be advantageous to perform a three-dimensional finite element analysis. This level of detail is up to the discretion of the designer. A three-dimensional analysis will reveal the overall structural response of main frame members in conjunction with secondary bracing, skin plates, intercostals, and diaphragms. This analysis will show contribution of secondary member forces to the total response of the structure. This was demonstrated in a three-dimensional analysis of the Ice Harbor Navigation Lock downstream vertical lift gate. Appendix B case histories provide more insight to the analysis of Ice Harbor as well as Lock and Dam 27. Attention should be given to the assembly of the model when meshing the skin plate to the framing members and, for the case of arched gates, the location of the intersection of the neutral axis of the main tension tie and the arch frame or truss. These will often be offset in the gate and will require special parameters in the finite element model. The same case exists for the connectivity of the skin plate to the upstream flange. In this case the plate and the structural member are modeled to join at a node. An offset parameter will be required to account for the eccentricity of the center of the plate to the neutral axis of the girder. One method to create the offset is to use kinematic constraints (rigid links or master/slave combinations) for connectivity of the central plane of the plate to the neutral axis of the frame. This is illustrated in Figure 6.1. Another method is to apply specified joint offsets if the software has this capability. Intermediate vertical diaphragms or diagonal bracing used to separate girders or framing members can add considerable stiffness to the gate; therefore, they should be considered in the analysis. Three-dimensional finite element analyses, using commercially available software, have been performed for the gates at Ice Harbor Downstream Navigation Lock and Lock and Dam 27. Both model studies were initiated to determine the structural response of the gate when cracking occurred in the main framing members. Upon complete failure of the tension girder, W840x359, (WF 33x240) in Ice Harbor's old gate (Plate 1), it was demonstrated in the analysis that the skin plate and arch frame added considerable stiffness to the gate that transferred load to the adjacent arch frames. With a two-dimensional analysis, the arch and tension tie indicated only plane bending and axial stresses in the tension tie girders. A three-dimensional analysis revealed out-of-plane (weak axis) bending as a result of diagonal bracing lacing the downstream tension ties. In some cases, this added about 35 MPa (5 ksi) to the overall stress in the main tension tie. In the case of Lock and Dam 27, a three-dimensional finite element analysis was helpful in determining the distribution of vertical loads between the skin plate and the downstream bracing, and thus the out-of-plane loads to the downstream girder flanges.

6-2. Component Design and Detailing

a. Skin plate. The skin plate can be welded directly to the upstream or downstream edge of the main horizontal framing member with continuous fillet welds and act as part or all of the flange, or be welded to the flange of a plate girder and used in combination. Design of the skin plate involves consideration of its function as a part of the girder flange as well as that of a load-carrying member transferring the water pressure to the girders. The latter function may be accomplished by action of the skin plate as a vertical continuous beam with reactions at the girder center lines, or as a number of rectangular panels with two opposite edges supported by adjacent girders and the other two edges supported by adjacent vertical diaphragms framing between the girders. Reference EM 1110-2-2105 for skin plate design criteria. Skin plates may be of uniform thickness for each gate section with little waste of material since the girder spacing and plate span decrease as the water pressure increases. Skin plate splices should be made in areas of low stress with full penetration welds and inspected by radiographic or ultrasonic inspection. It is not considered necessary to add an allowance for corrosion to the designed thickness of skin plate. Smaller vertical lift gates can be removed for maintenance and painting; however, with improvements in paint systems, this requirement is no longer necessary.

b. Plate girders. Plate girder arrangements consist of a horizontal web plate with a skin plate on one side and flange plate on the other side framing into end posts. The girder spacing and flange width should assure that there is adequate space between flanges to allow access between girders for fabrication, painting, anode installation, inspection, and maintenance. The clear span of the girders is the distance between the center line of the bearing supports on either side of the gate. They are designed as simply supported members using the strength requirements in EM 1110-2-2105.

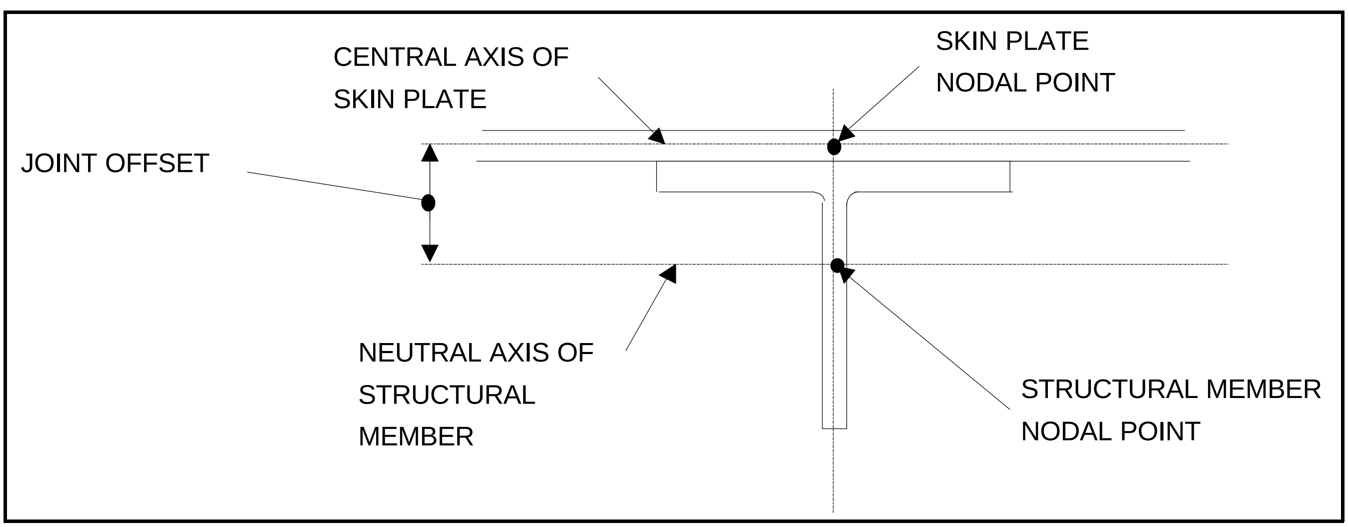

Figure 6-1. Joint offsets for plate to girder mesh

Transverse stiffeners shall be designed in accordance with the requirements specified in AISC (1995). Longitudinal stiffeners, if used, shall be proportioned in accordance with the appropriate paragraphs in AASHTO (1996).

c. Trusses. The design of the truss requires that secondary stresses be minimized by assuring that the connection of truss members coincides with the centroidal axis of the members at the joint. The effects of secondary stresses that are caused by stiffness, restrained joints, and excessive deflections require correct evaluation and proper detailing to increase the fatigue life of the structure. Combined compression plus bending will occur when the compression chords are welded to the skin plate or the skin plate is used in combination with the compression chord. A reduction of negative moments in the truss is not recommended for continuous members. To determine the stability of the tension chords under stress reversal, loads acting on the reverse side shall be investigated. These may include wave runup, wind loads, or in the case of hurricane or tide gates, effects of reverse hydrostatic loads. Vertical bracing, distributing loads from the downstream chord, helps distribute the horizontal truss loads and support the vertical loads applied to the gate or throughout its movement. Recent studies reveal considerable stiffness in the vertical trusses that can create adverse stress conditions in the gate framing. Therefore, care should be used when analyzing and accounting for attraction of additional stiffness at the joints. The degree of fixity will determine the appropriate value of equivalent pin ended member of length KL as specified by the AISC (1995) for compression members. Deflections should be investigated to determine the effects of tolerances for the gate slot depth and width, as well as upstream or downstream clearances. Camber should be considered where live load deflection will cause tolerance problems.

d. Tied arch members. Design of the main tension tie requires the consideration of weak axis bending and torsion. Mud and ice resting on the web as well diagonal and vertical bracing make a significant contribution to this type of loading. In addition, emphasis should be given to the load path from secondary bracing. The secondary bracing may have a direct load path to the tension ties, which will induce weak axis bending in combination with tension from the arch. Proper detailing of fracture critical connections to the tension tie is important to the service life of the gate. The applicable sections of the AISC (1995) steel manual shall be used for determining the effects of members under tension, torsion, and other combined forces. Where the girder webs are resting horizontally, drainage holes need to be sized and spaced accordingly to eliminate weak axis bending, to reduce the weight to the operating machinery, and to prevent maintenance problems.

e. Intercostals. Intercostals span between main horizontal framing members to stiffen the skin plate and take advantage of two-way plate bending action. Their use may not be required where main framing members are closely spaced. Intercostals may be single bar or plate, or angles of unequal leg sizes. Load distribution and design rationale for intercostals are presented in EM 1110-2-2105 and shall be used for vertical lift gates. Proper detailing should consider the fracture and fatigue life of the intercostals and their contribution to the skin plates, girder flanges, and webs.

f. Diaphragms. Vertical diaphragms transfer horizontal loads to the girders and cause the gate to deflect more uniformly. They also support and distribute vertical loads. Hoisting equipment is located along the line of diaphragms to transfer the vertical hoisting loads.

g. End posts, end bearing. The end bearing transfers the girder reactions from bearing shoes, wheels, and rollers to bearing plates or tracks on the pier. Horizontal girders transfer load through shear into end posts. End posts may be single girders supporting cantilevered wheels or rollers, or double girders with wheels mounted on pins bearing on both sides. Two types of bearing conditions can occur. One type provides bearing directly from the rollers as a series of point loads or from wheels as a single point load. The other type relies on a bearing shoe mounted to the gate to transfer loads to the bearing plate. This type requires a recess in the guides to prevent the wheels from transferring hydrostatic load, allowing the bearing shoe to transfer hydrostatic load to the bearing plate. This becomes advantageous when loads are too great for wheel point bearing transfer, as with navigation lock gates.